SkySat Initial Radiometric Correction and Radiometric Calibration

Andreas Brunn, Adrian Gonzalez, Karim Lenhard, Sara Bahloul,
Joshua Grennberg, Nicolas Smith, Ellyne Kinney-Spano, Ignacio Zuleta

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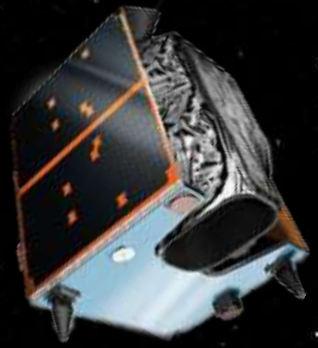
Desert Patterns, Saudi Arabia – May 30, 2016

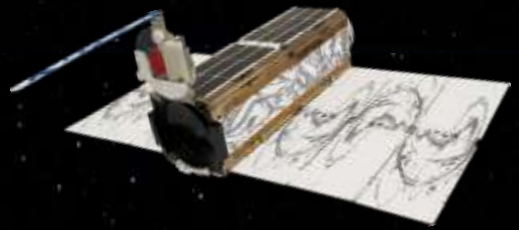
What am I talking about today?

- Planet and SkySat
- Radiometric Corrections (Flat Fielding)
- How do we achieve absolute calibration
- Vicarious Calibration
- Cross Calibration to other SkySats

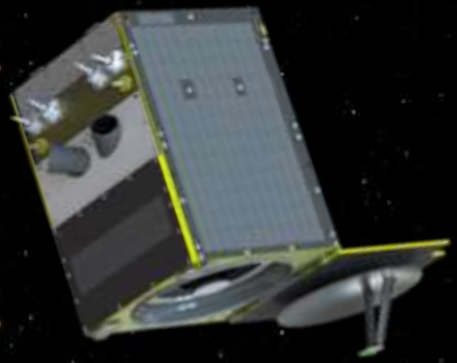
PLANET'S CONSTELLATION



5 RapidEye Satellites



130+ Dove Satellites PlanetScope



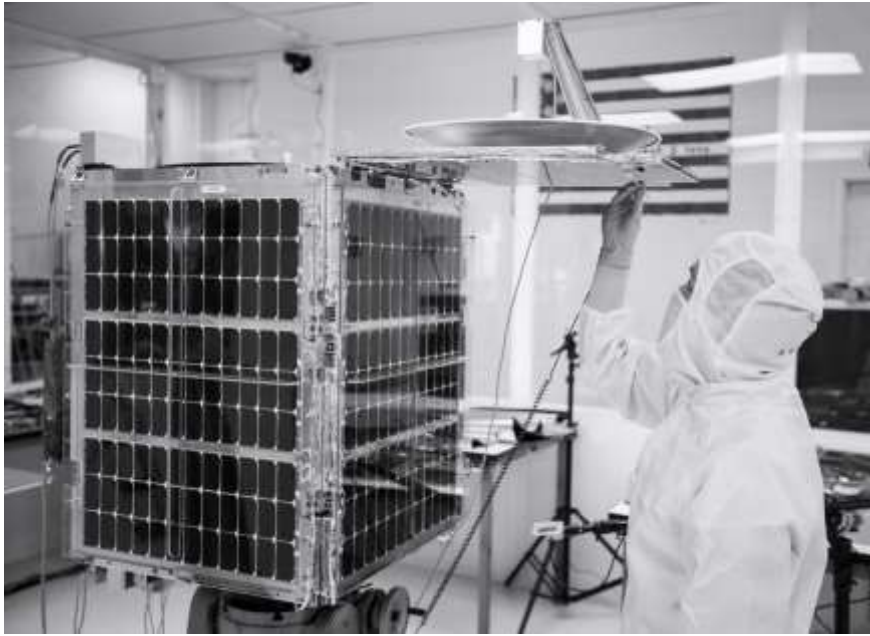
13 SkySat Satellites

OUR CONSTELLATIONS

Constellation	Dove	RapidEye	SkySat
Orbit Altitude	475 km	630 km	500 km
Spacecraft #	130 +	5	13
Image capture capacity	300 million km²/day	6 million km²/day	500K km²/day
GSD (Nadir)	3.9 m	6.5 m	0.72 m PAN
Pixel Resampled	3.125 m	5 m	1 m
Telescope and Camera	Bayer mask CCD sensor	Push broom imager TMA telescope	CMOS Frame Camera with Cassegrain telescope
Spectral Bands	RGB and NIR	RGB, Red Edge and NIR	RGB, PAN and NIR

SKYSAT AT A GLANCE

- SkyBox Founded in 2009 by 4 Stanford grad students
- Raised $110M over 3 financing rounds from local VC’s
- Google Acquisition July 2014
- Planet Acquisition May 2017
- 13 satellites launched, all collecting imagery daily, operating 24x7 from Mountain View, CA
- 2 satellites scheduled for launch in Q4 2018



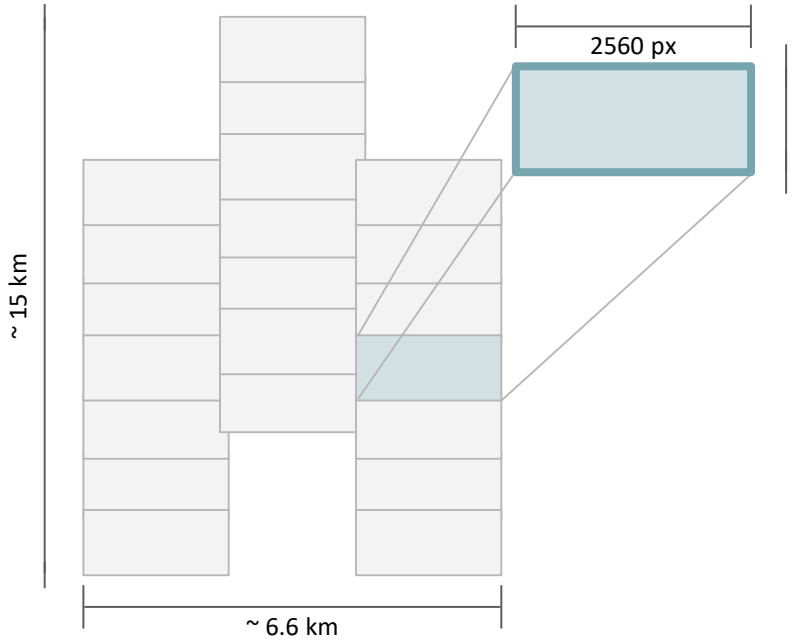
INTRODUCING THE SKYSATS

Satellite Bus	
Attribute	**Value**
Mass	110 kg*
Dimensions	60 x 60 x 95 cm*
Total DeltaV	180 m/s*
Design Life	~6 years
Revisit (all SkySats)	Sub-daily
Constellation	**1** - SkySat 1 launched Q4 2013 **1** - SkySat 2 launched Q2 2014 **1** - SkySat 3 launched Q2 2016 **4** - Skysats 4 - 7 launched Q3 2016 **6** - SkySats 8 - 13 launched Nov 2017
Upcoming Launch	**2** - SkySats 14 – 15 Q4 2018

**SkySat-C Class*

SKYSAT CAMERAS

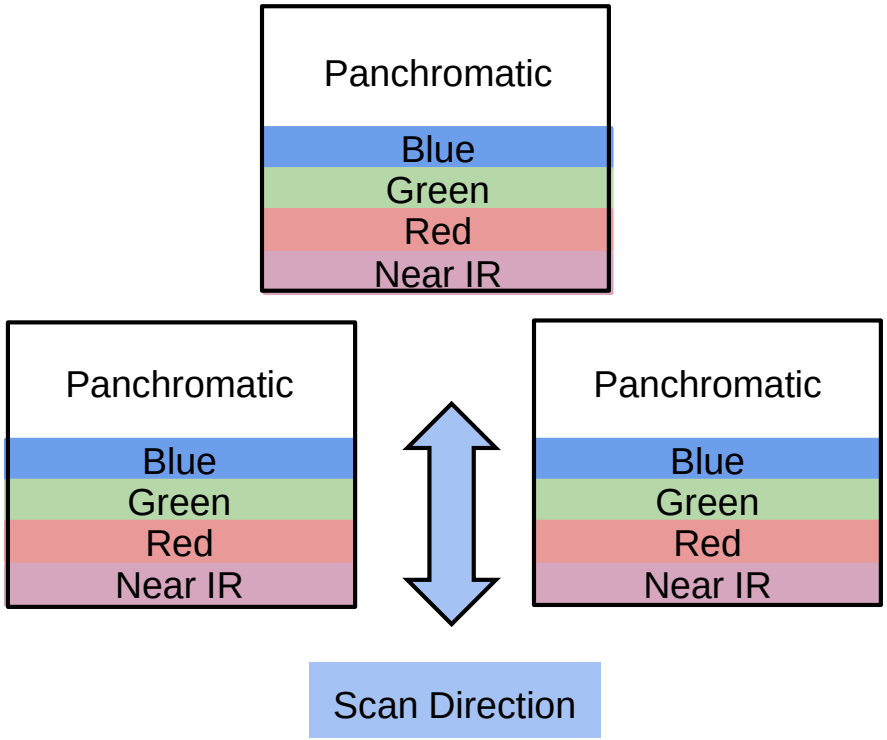
Camera Attributes	
Attribute	**Value**
Image Configurations	Multispectral Sensor (Blue, Green, Red, NIR)
	Panchromatic Sensor
Sensor Type	CMOS Frame Camera with Panchromatic and Multispectral halves
Spectral Bands	Blue: 450 - 515 nm Green: 515 - 595 nm Red: 605 - 695 nm NIR: 740 - 900 nm Pan: 450 - 900 nm
Product Framing	SkySat Satellites have three cameras per satellite, which capture overlapping strips. Each of these strips contain overlapping scenes. One scene is approximately 2560 x 1080 pixels. (see right graphic)



*Individual **scenes** above*

PUSHFRAME IMAGING

- Collect short exposure (400 - 19000 us) overlapping images
- Use image registration & reconstruction to generate final full color imagery
- Improve both SNR and ground sample distance (GSD) with super-resolution (pseudo tdi)
- Compress and transmit to the ground
  - JPEG 2000 compression on board (potentially lossless)



Radiometric Corrections

- Dark Fields
  - Images created during commissioning phase before the camera door has been opened
  - Used to create the dark pixel offsets for flatfielding
  - Used to detect malfunctioning pixels
  - Changes after commissioning can be detected using a large subset of dark images from standard imaging

Radiometric Corrections

- Flat Fields
  - Images of bright and homogeneous desert and cloud images are collected
  - Mean brightness created as average of all suitable images substracted by the dark field offset
  - Used to create the per pixel gain for flat fielding

=> Dark field offset and flat field gains form the per pixel correction function

Vicarious Calibration

SkySat doesn’t have have “fancy equipment” to support calibration activities

Uses ground measurements on homogeneous sites while a satellites flies over the site and captures an image.

Atmospheric- and ground properties are measured to simulate the at sensor radiance on site

RadCalNet

- RadCalNet is a network of four robotic reference stations
- https://www.radcalnet.org/#!/
- Freely available measurements on 4 homogeneous sites
- Daily measurements every 30 minutes between 9:00 and 15:00 (local)
- Spectral coverage between 400 and 2500nm

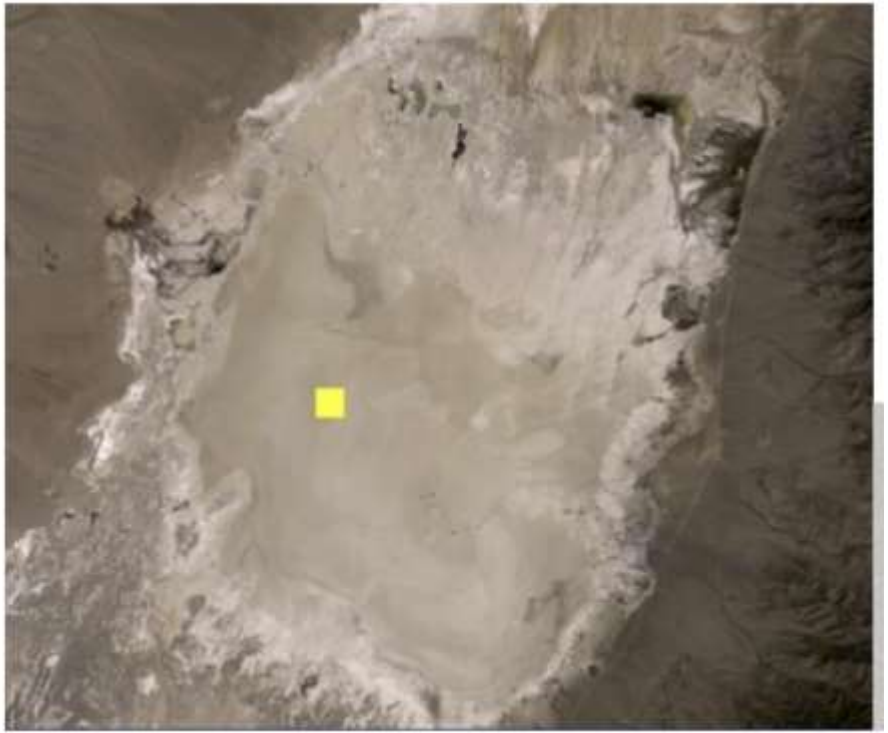
RadCalNet Sites

Railroad Valley

Homogeneous salt flat site

Size 1 km x 1 km

Loooong heritage for vicarious calibration purposes



RadCalNet Sites

La Crau

Homogeneous dry grassland site in southern France

Spectra represent a disk of 30 m diameter

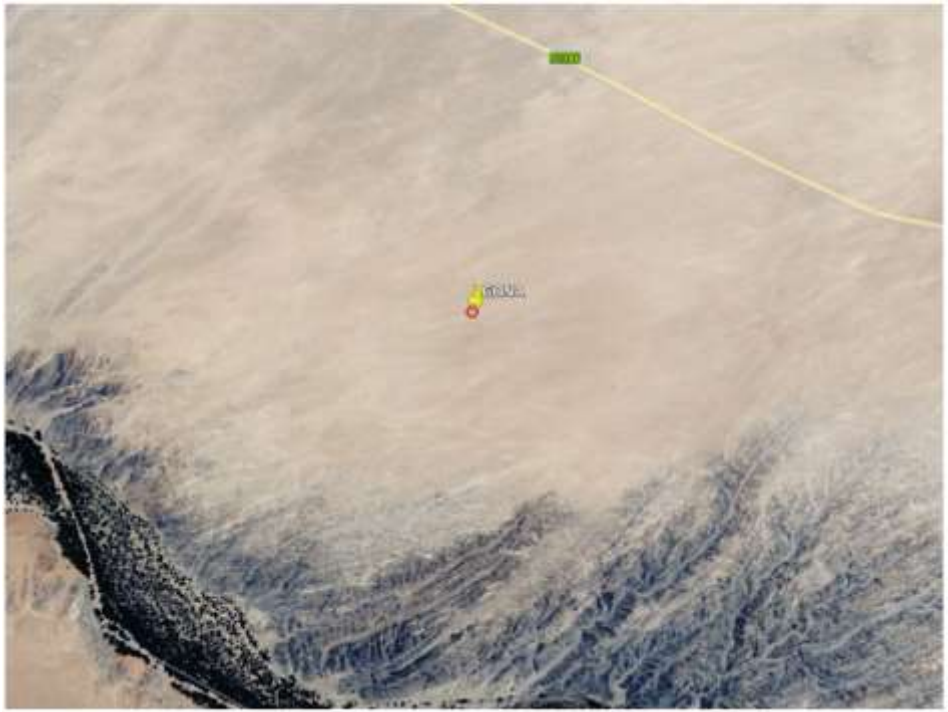
RadCalNet Sites

Gobabeb

Homogeneous desert site in Namibia

Data since 2017

Spectra represent a disk of 30 m diameter



RadCalNet Sites

Baotou

Artificial gravel target in China

Chessboard pattern with three different Shades (2 * white, grey and black)

Radcalnet spectra represent the grey area

RadCalNet Sites

Baotou

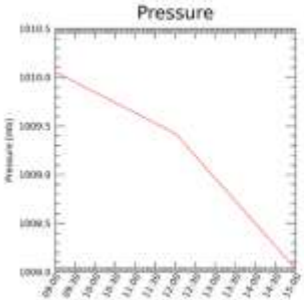
NOT USED

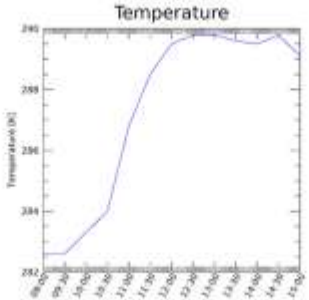
Artificial gravel target in China

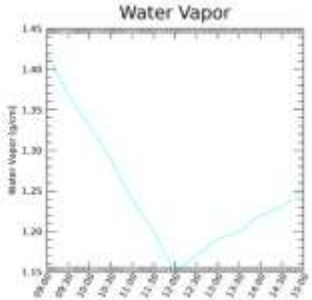
Chessboard pattern with three different Shades (2 * white, grey and black)

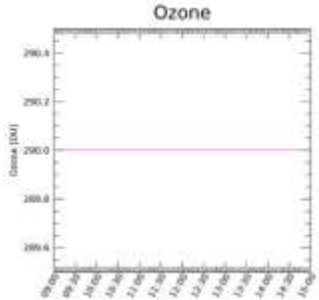
Radcalnet spectra represent the grey area

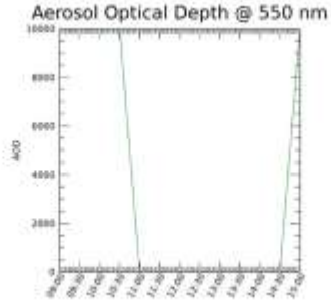
Atmospheric Information

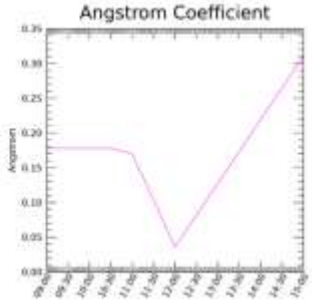








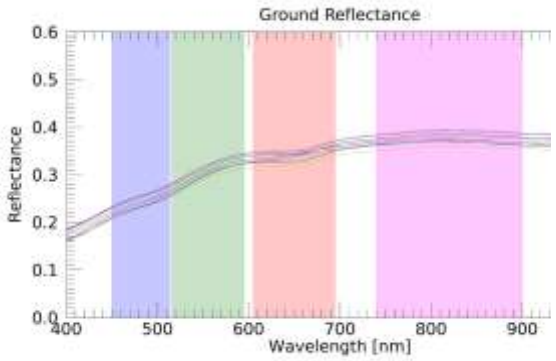




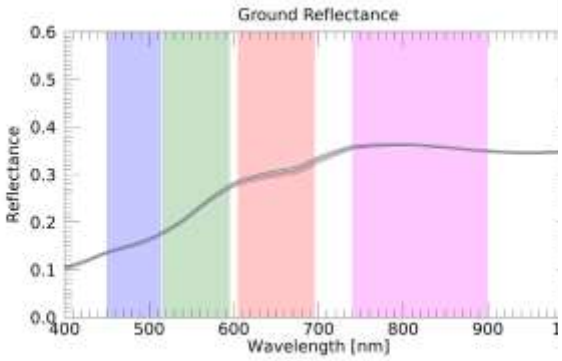
- Air pressure [mb]
- Temperature [K]
- Water Vapor [g/cm^3]
- Ozone [DU]
- Aerosol Optical Depth @550 nm
- Angstrom coefficient

In 30 minute intervals between 9:00 am and 3 pm
(13 measurements daily)

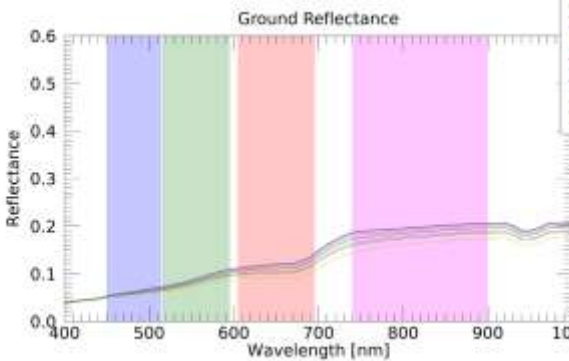
Ground Reflectance



Railroad Valley



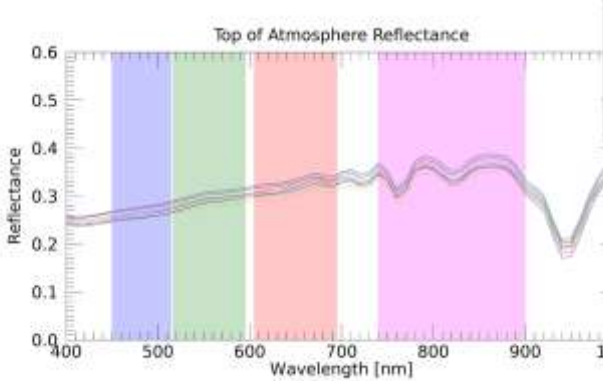
Gobabeb



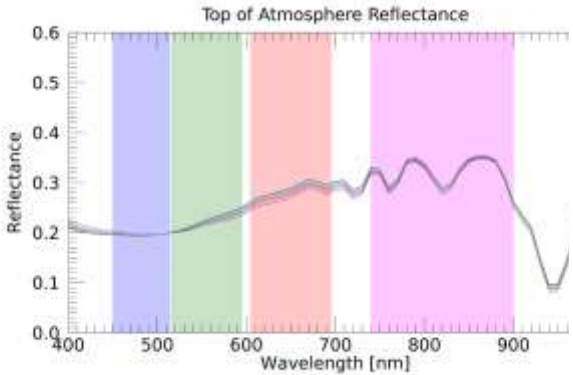
La Crau

Surface Reflectance together with atmospheric information is used in MODTRAN 5 to model top of atmosphere reflectance using a standardized RADCALNET procedure

Top of Atmosphere Reflectance



Railroad Valley



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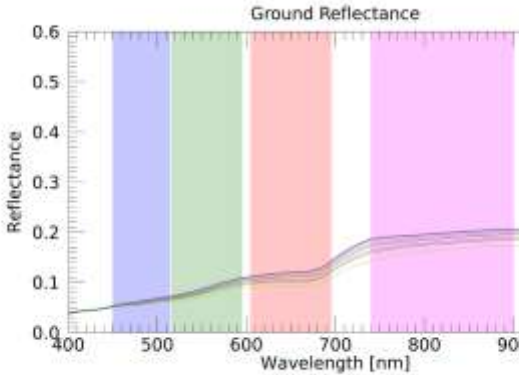


La Crau

Three different brightness levels allow line fits between Satellite and Ground Data
This dataset is used for absolute vicarious calibration!!!

Planet Procedure for SkySat

All RadCalNet info is stored in the cloud

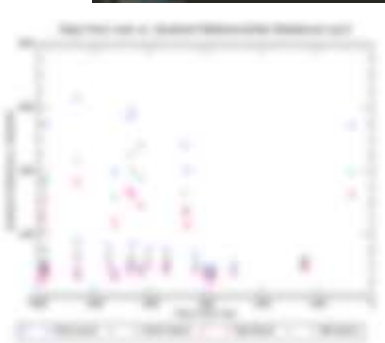
Python script has been developed to:

- search the archive for crossover collects (within 15 minutes of RadCalNet datapoint)
- Orthorectify frames
- Subset frames to the actual subset of the RadCalNet data
- Report creation for each individual crossover for all sites

Planet Procedure

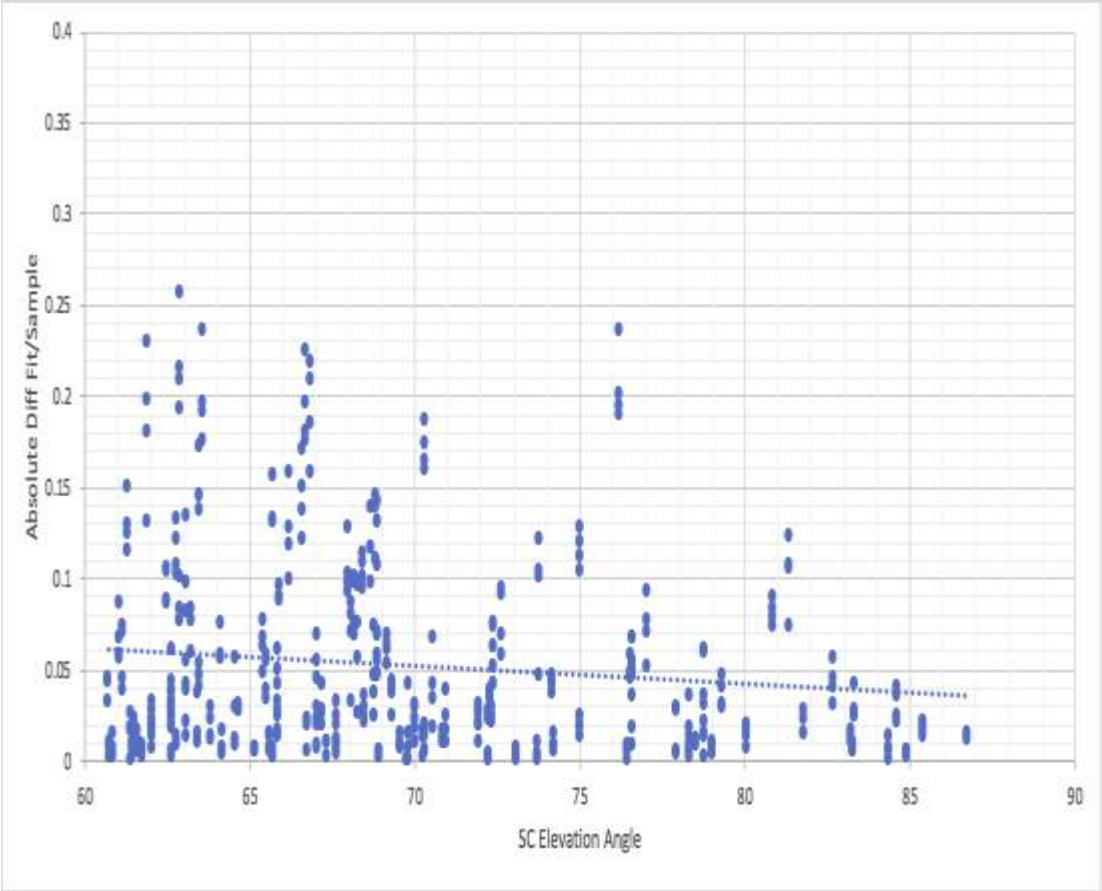
IDL Script to analyze the results

- Python script report as input
- Plots per Sat/Band, fits between image DN (corrected by integration time) and reference
- Detects outliers
- Visualizes other analytics like error/look angle dependency, time trends, …
- Calculates gains and offsets to transfer DN into Radiance
- Creates per file and sat/band reports



Results

- Sufficient sample size only for SkySat 1 to 7 satellites (excluding the Sats launched in Nov. 2017)
- Uncertainty increases with increasing Satellite roll angle

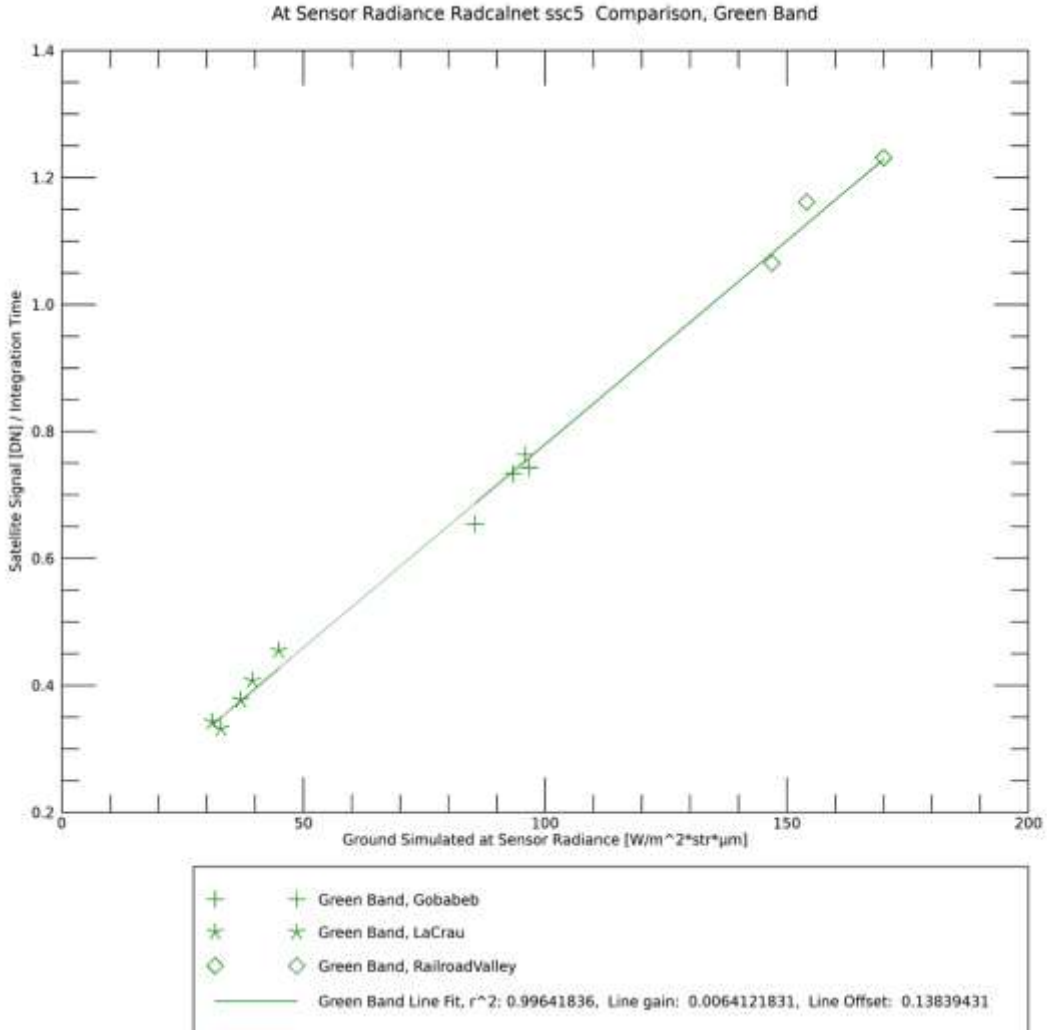


Results

Plots like this for every band and satellite

Three calibration sites in common form a line through a wide range of brightness levels

Gain and offset of the line equation form the calibration parameters to convert DN normalized by integration time into radiance units



Results

	S1	S2	S3	S4	S5	S6	S7
Blue	8.48	3.57	9.46	6.49	5.44	6.79	2.63
Green	8.59	8.54	6.85	5.35	5.69	5.33	2.35
Red	6.89	5.7	8.53	5.86	5.04	7.61	2.34
NIR	7.57	4.63	6.52	6.1	4.57	5.37	2.44
Samples	18	11	18	15	9	11	14

Mean % absolute difference between the measurement and the fit

Cross Calibration between SkySat generations

While there is sufficient RadCalNet reference for the first launched sats (up to C5) it is not for Block 2 C Class satellites

Cross calibration between the satellite generations is used to cross calibrate Block 2 to Block 1

- As there is no significant difference in RSRs between Block 1 and Block 2 C class sats => no SBAFS necessary
- Brightness difference due to different overpass times can be corrected using Lamberts cosine law

$$E_\theta = E * \cos(\theta)$$

- No other corrections (like e.g. BRDF) is applied to the data

Cross Calibration between SkySat generations

A tool has been developed that uses selected crossovers (same day) to derive calibration coefficients

- Identify and mosaic overlapping areas of different crossovers of different homogeneous sites (Libya4, LaCrau, DomeC)
- Correlate the overlapping area of Block 2 sats to the Block 1 sat radiance
- Correct for sun elevation influence
- Calculate correction parameters (gains and offsets)
- Calculate the quality measures

C6 DN

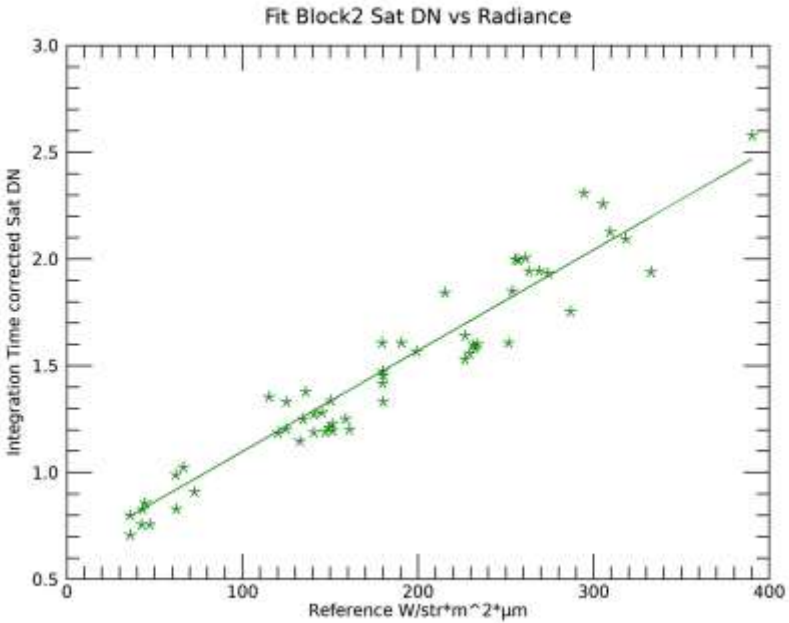
S02 Radiance

Results

Plots like this for every band and satellites

Gain and offset of the line equation form the calibration parameters to convert DN normalized by integration time into radiance units

Higher uncertainty than the direct comparison to RadCalNet sites



Results

	S8	S9	S10	S12
Blue	5.70	3.48	6.01	5.86
Green	5.85	10.23	4.95	10.44
Red	5.19	7.85	4.44	4.45
NIR	2.98	9.64	6.42	10.40
Samples	10	10	23	7

Mean absolute % difference between the measurement and the fit

Conclusion and Next Steps

- All SkySat satellites and bands are initially calibrated to an uncertainty of 10% or better
- Improvements through transfer of Block 2 sats to the RadCalNet method
- Add the Brookings cal site once 2018 data becomes available
- Combine this method with Cross Validation to RapidEye, Landsat8 and Sentinel2
- Extend samples size (and hopefully increase accuracy) with new RadCalNet data (once it becomes available)

Thank you very much

andreas.brunn@planet.com

Sydney, Australia, SkySat
Off Nadir Image

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